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The conversion of mapping technology in the DOD community from analog-to digital-based technology, which started in the 1980's required precise equipment to convert aerial photographs to digital data (pixels). These are referred to as image scanners or digitizers. This paper describes the recent development of a precise image scanner by the Topographic Engineering Center (TEC) (formerly ETL). A contractor successfully developed this scanner, called the Image Digitizing System (IDS). This paper describes the general design and operation of the system, and many of its unique characteristics. The paper also describes several test results, that verify the high-geometric and high-photometric characteristics of the IDS.

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The Image Digitizing System (IDS)

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Abstract: The conversion of mapping technology in the DOD community from analog- to digital-based technology, which started in the 1980's required precise equipment to convert aerial photographs to digital data (pixels). These are referred to as image scanners or digitizers. This paper describes the recent development of a precise image scanner by the Topographic Engineering Center (TEC)(formerly ETL). A contractor successfully developed this scanner, called the Image Digitizing System (IDS). This paper describes the general design and operation of the system, and many of its unique characteristics. The paper also describes several test results, that verify the high-geometric and high-photometric characteristics of the IDS.

INTRODUCTION

Image Scanners or Image Digitizers convert aerial photographs into digital images, which can be processed in computers. TEC undertook the development of a low-cost digital mapping system, called the Terrain Information Extraction System (TIES), in 1988. This system requires a precision digitizer to provide digital images as one source of input to the Digital Stereo Photogrammetric Workstation (DSPW), the main component of TIES.

The primary requirement for this digitizer is to provide accurate input to the workstation in order to produce accurate data bases for Army use.

In 1989 TEC awarded a contract to build a unique and very precise image digitizer. This digitizer/scanner is called the Image Digitizing System (IDS). The optical-mechanical portion and its controls are a modification of an analytical plotter. An illumination system, CCD camera, computer with its peripheral equipment, and the digitizing software were added.

SYSTEM DESCRIPTION

The IDS consists of four modules: a scanner module, a computer rack, a 27-inch color monitor, and a 1600/6250 bpi 9-track magnetic tape drive.

Scanner Module: The scanner module contains a precise flat-bed table, illumination system, a CCD camera, and an

The table consists of x and y stages with a 10.5- by 10.5-inch photo carriage on the x or upper stage. This stage rests on the y stage and both transport the input material using precision leadscrews and servos/encoders/tachometers. A linear precision measuring system has been added on the lower stage (y) to control the CCD integration along the scan axis. The scan is performed approximately (taking into consideration the rotation capability) parallel to the y axis. The scanning area of the table is 10.25 by 10.25 inches (261 x 261 mm). The resolution of the leadscrews/encoders is 0.25 micron and the table is accurate to less than 2 microns root mean square error over the 10.25-inch distance of each axis. This accuracy is obtained during the scan using a linear correction program to correct the very small x and y scale and mis-perpendicularity errors between the two axes.

The photo carriage has a precision glass plate on which rests the input material with the emulsion down. A glass cover plate with three clamps holds the input material in place at the optimum scanning plane. The maximum film sheet size that can be placed on the photo carriage is 10.5 by 10.5 inches. The maximum scanning area is reduced by the rotation of the scan. For a rotation of 5 degrees, the maximum area is reduced to 241 by 241 mm.

A calibration patch is located on the rear-center position of the y carriage, and consists of a small glass plate with three densities, 0.0, 0.2 and 2.0. This calibration patch is at the same plane as the input scanning plane. During the normalization operation the 0.2 and 2.0 density patches are scanned and the data are used to normalize the 2048 pixels of the linear CCD array.

The illumination system uses a specular design to focus the light. It consists of a halogen light source and a four position filter wheel. A fan exhausts the heat from the lightsource from the cabinet. The filter wheel contains a clear, a red, a green, and a blue filter. Adjustment means are provided to shift the light source in the optical system to provide optimum linearity of all pixel intensities of a normalization scan of the .2D calibration patch. A fiber optic cable is connected from the illumination system to a prism and condenser lenses, located above the table at the optical axis position. From there the light travels down through the input material, through a specially designed "zero error" lens, to the CCD camera. A shutter is located between the lens and the CCD camera.

The CCD camera uses a 2048-element linear array with each element 13 by 13 microns in size. This array is positioned so that each element represents a 7.5- by 7.5-micron area at the image plane. The swath width of a single scan is thus 2048 by 7.5 or 15.36 mm. The camera is located on a turret to provide a plus and minus 10-degree rotation capability, controlled by a 40,000 count circular encoder/servo/tachometer. The two carriages of the table move very precisely along a vector determined by the rotation angle to produce one or more swaths of digitized data. The combined carriages always travel along a vector perpendicular to the linear array.

The electronics chassis controls the scanner and the illumination system. It uses a micro processor to communicate with the computer. This chassis and the illumination system are located on the lower level of the scanner cabinet and the table and CCD camera are located on the upper level. A heat shield is located between the two levels. The chassis has a multi-fan exhaust system which by means of a baffle also exhausts air around the CCD camera to provide adequate cooling for the camera.

Computer Rack: The computer rack houses the computer with an internal RAM memory of 64 Mb, two 670 Mb discs, a CDROM drive, a 3.5-inch floppy drive, and an 8-mm cartridge tape drive. An external 1 Gb disc drive has been added.

Color Monitor: The color monitor has a 27-inch two-megapixel (1664 x 1248 pixels) display with a 24-bit graphics processor (8 bits per color). A keyboard and a mouse are used to control all operations. The monitor is fastened to a special stand with height and angle adjustments.

Tape Drive: A standard 1600/6250 bpi 9-track magnetic tape drive provides the means to store data on regular 9-track tapes. As more customers purchase Exabyte tape drives, the 8-mm cartridge tape drive will be used more often to store image data.

An internal network is also present to move data directly to other TIES components, such as the Digital Photogrammetric Workstation.

The operating system is an implementation of UNIX System V from AT&T. The application software has been upgraded several times during the past two years. It is primarily an icon-driven package with many capabilities to enhance and speed up the scanning process.

The IDS is considered a *true photogrammetric scanner* because it has the capability to perform interior orientation at the highest resolution possible, to store all coordinates of the measured fiducial/reference marks and corners of the scanned patch in a header file, and to provide image data at a high-photometric accuracy.

SYSTEM OPERATION

Film Preparation: It is advisable to have a light table to inspect the photograph to be scanned, and to record information for the files to be created. This information or data, required for photogrammetric workstations, consists of camera orientation, calibrated focal length, the emulsion side of photo, and the desired orientation of the photograph on the scanner. The camera orientation is the location of the data block with respect to the positive flight direction. The calibrated focal length is read from the data block. The emulsion side of the transparency is found to select either a right-handed or left-handed coordinate system to scan the transparency (the emulsion is always placed against the glass plate).

Film Loading: The photog[illegible] dusted with a lens brush before loading. It is normally loaded with the flight direction along the positive x-axis of the table, emulsion side down (positive y in reverse direction). This allows a model to be viewed on a photogrammetric workstation in the proper orientation.

Film Scanning: The IDS is operated by clicking with a mouse on menu buttons seen on the monitor. These call up forms with several windows for entering data, scroll through files, or activate switch settings. Normally the operator either calls up saved files or creates new files pertaining to the photo to be scanned. The two main forms are the "Scan Setup and Control" (Fig.1) and the "Photo/Camera Type Definition" (Fig.2). The first is the form required to perform any image scan. The second is primarily for interior orientation but also controls positive y direction and cursor density. In this file are listed all reference points to be measured.

Once all forms are filled in, the first operation required before any scanning is to calibrate the CCD camera. This is done with a normalization operation. The second operation, if photo alignment or interior orientation is required, is to perform the interior orientation operation. If neither is required, the interior orientation operation is skipped and an image scan operation is then performed.

Normalization. The first operation of the IDS is to scan the calibration patch to normalize the 2048 elements of the CCD array. This is done for both the light and dark boundaries of the provided density range (0.2 - 2.0). The produced 0.2D and 2.0D scans can be shown on the monitor during equipment calibration, where their pixel intensities can be measured in order to check the illumination level or illumination linearity across the whole scan width. Once the normalization is completed, the results are shown in the window where the operating system is running and the system is ready to perform any type of scan.

Interior Orientation. This operation is available for those users of digital data, who require it either for creating math models on photogrammetric workstations or only to align the scan axis to the photo coordinate system or any other coordinate system. Once this menu is selected, the computer uses the file of fiducial points (maximum of 25 pts) in the Photo/Camera Type Definition form as prepositioning data to drive automatically to their positions. Each fiducial is scanned in sequence as a small patch (appr. 15x15 mm) at the highest resolution (7.5 microns). The point is measured on the monitor after each scan with the cursor, controlled by the mouse, at a precision of 1/10 of a pixel. The image can be enlarged before measuring to increase the accuracy of point measurement.

A part of this operation is an alignment of the scan axes (by rotation of the CCD camera and table travel in a vector perpendicular to the linear array of the CCD camera), performed in the software by the use of a least square "rigid body" fit between the given and the measured coordinates of the fiducials. The [illegible] coordinates [illegible] acting as prepositioning [illegible], used to drive the table to their coordinate positions. They are normally the fiducial coordinates obtained from a calibration report of the camera, but they can also be nominal values of the fiducials. This file of fiducials can be rotated to any of the four cardinal directions before measuring to align the measured fiducials with the calibrated fiducials. The transformation corrects the first measurement for translation, the second for rotation, and any more points assigned to be used in this fit provide iterative small adjustments. Fiducials can be used in the alignment, or they can be measured without affecting the alignment.

The coordinate origin can with a translation be moved to any desired position. At the completion of the measuring operation, a table is shown with residuals between the given coordinates and those measured, plus their root mean square accuracy data. Both the input and output files of the measured points are placed automatically in the header file.

Image Scanning. Image scanning is always performed at 7.5-micron resolution. The CCD camera scans produce 10-bit pixels of which the best 8 bits are selected for storage. In addition to storing 7.5-micron pixel data, data can by pixel aggregation be stored at binary multiples (15, 30, 60, and 120 microns). Normally 30- or 60-micron resolution pixel data is selected. Left-handed coordinate images can be scanned as right-handed coordinate images by reversing the scan along the y-axis. Data (pixel intensities) can be produced in either transmission (linear) or density (logarithmic) mode. In addition negative images can be scanned to produce positive digital images.

A histogram is produced and shown for each image scanned and provides the means to check and adjust the proper integration time. A small test image is first scanned to determine the optimum integration time for that particular exposure, if not known. The integration time for scanning a particular photo image is selected to spread pixel intensities across the full 255-count range to achieve a bell shape. With one iteration, normally, the optimum integration time is found and will be valid for all photographs taken for a project.

Several windows on the Scan Setup and Control form need updated information before scanning the desired image area or patch. The image patch lower left and upper right photo coordinates are keyed in, together with the file name, directory, resolution, and several other support items. Image data are stored in a tile format. Tile sizes available are from 32 to 1024 (binary multiples), with 128 being the default size. Eight output file formats are available for selection. Three are unordered tile formats; one is an ordered tile format without a header, which is used as an input to the photogrammetric workstation; three are JPEG compressed formats; and the last is a TIFF standard format.

Once all the data have been entered, the operator initiates the scanning operation. A form shows data of [illegible] number of [illegible] that [illegible] and the present swath number being scanned. This information and the selected pixel size provide a means to estimate the length of the operation. At the completion of the scan, a decimated image of the scanned image is displayed on the monitor, together with an overview window, and a histogram window. The operator can inspect the quality of the data and decide to save or delete it.

Color images are scanned by sequential scanning through the red, green, and blue filters. An automatic adjustment of the integration time occurs to compensate for the differences in transmission efficiency for each filter. The three separate scans constitute a color image, thus three times more data than for a black and white image.

Many customers for digital data require a straight raster format. Off-line conversion programs are available to convert the scanned image file to a raster format.

Header File Creation. A header file is created for each image file. It has all the required support information in a ASCII format and is based on key word/phrase and value(s) structure. Many items, such as fiducial coordinates, image patch coordinates, selected resolution, tile size, image size, selected filter, scan date and time are automatically placed in the header file. Other data can be added by the operator. These relate to camera data, geographic location, photo quality, cloud coverage, etc.

DISCUSSIONS

Storage. In a production environment, storage is a major problem. A full-frame photo at 30-micron resolution equals approximately 57 Megabytes. For a color photo it is 171 Mb. For 60-micron resolution data, the storage is reduced four times. Also converting files to other formats doubles the file size temporarily (The original format file can be erased after the conversion). The operator needs to be constantly aware of how much storage remains, especially for large files, and periodically move files onto tapes or via the network to other systems.

Scanning Speed. The speed of scanning depends upon three factors. The first is whether an interior orientation or a scan alignment is required. Depending upon the number of points to be measured, this operation takes about 5 minutes. The second is the resolution of the scan. The higher the resolution, the longer the scan time. The third is whether the boundaries for the scan are known ahead and stored in the appropriate file. If not, an overview scan of an area larger than required is done at the lowest resolution pixel (120 microns). The desired boundaries are then measured in the photo coordinate system on the displayed image with a special menu available from the screen's menu bar. The displayed coordinates on the screen's message field are then entered in the appropriate file. Normally the files for a [illegible] of time, [illegible] the fiducial calibration list for a certain camera, and the desired directory for storage. These files can be saved, thus saving the time for recreating them the next time they are required. On the average a photo can be scanned, including interior orientation, in 15 to 20 minutes.

The IDS was placed in operation at TEC in October 1990. Since then it has been used to scan all types of imagery for various customers and to test its application software as software improvements became available. The application software has been upgraded several times during the past two years.

TEST RESULTS

The IDS has been tested since its installation to determine its photometric and geometric accuracies.

For the photometric accuracy, the linearity of the illumination system has been tested by measuring the pixel intensities of scans of the calibration patch during the normalization operation and with a regular scan. The linearity is approximately 20 percent (plus or minus 10 percent from the mean) over the full-scan width when measuring pixel intensities along the full width of the scanned and displayed .2D calibration patch. After the normalization operation is completed the same area on the calibration patch was scanned. Variations in pixel intensities were only plus or minus one count (bit) for both the light and dark wedges.

For the geometric accuracy, a precision grid has been measured in various menus. Both 9 and 25 point grid tests have been performed periodically, showing less than 2-micron RMS error per axis. Grid scans have also been used to determine the accuracy of alignment of adjacent swaths, both in the width and rotation vector. No errors in width or rotation were discernable. The resolution of changes in the adjacent grid line position, that can be seen on the monitor is approximately 1 micron.

Resolution tests show that the maximum resolution (67 line pairs per mm) required for viewing the smallest pixel size is achieved over the whole format. Resolution patterns were placed in the four corners and in the center, scanned at the maximum resolution and read on the monitor.

The reliability of the IDS has been excellent. Since its installation, no mechanical or electronic failures have occurred in the scanner itself. The applications software is operational and employs many good human engineering principles. Overall the IDS has proven to be a unique and successful development and the quality of its products is unsurpassed.

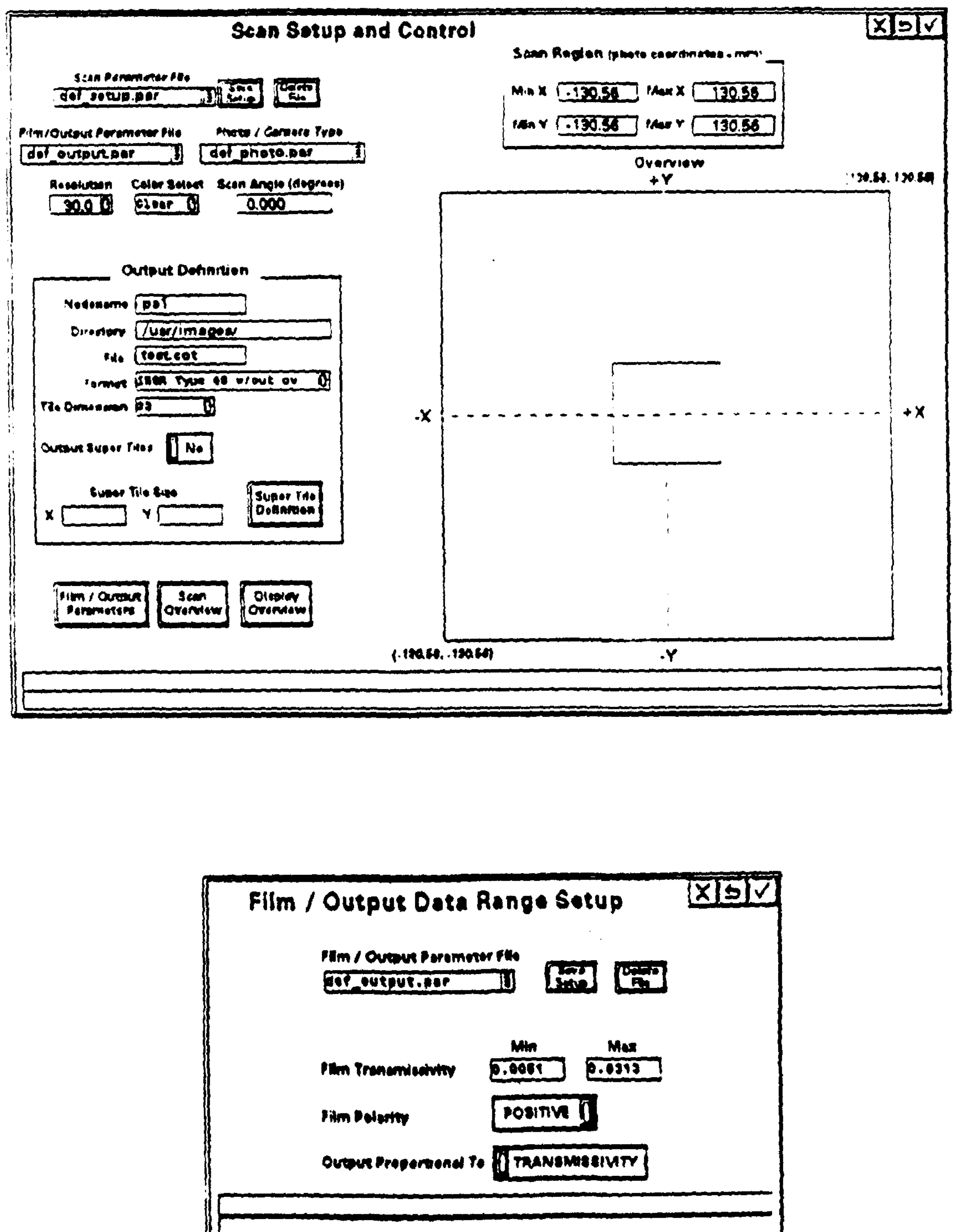
Scan Setup and Control
Scan Region
Min X
-130.56
Max X
130.56
Min Y
-130.56
Max Y
130.56
Scan Parameter File
def_setup.par
Film/Output Parameter File
def_output.par
Photo / Camera Type
def_photo.par
Resolution
30.0
Color Select
Clear
Scan Angle (degrees)
0.000
Overview
+Y
-X
+X
-Y
Output Definition
Nodename
Directory
/usr/images/
File
Format
Tile Dimension
Output Super Tiles
No
Super Tile Size
X
Y
Super Tile Definition
Film / Output Parameters
Scan Overview
Display Overview
Film / Output Data Range Setup
Film / Output Parameter File
def_output.par
Save Setup
Delete File
Min
Max
Film Transmissivity
Film Polarity
POSITIVE
Output Proportional To
TRANSMISSIVITY

FIG. 1

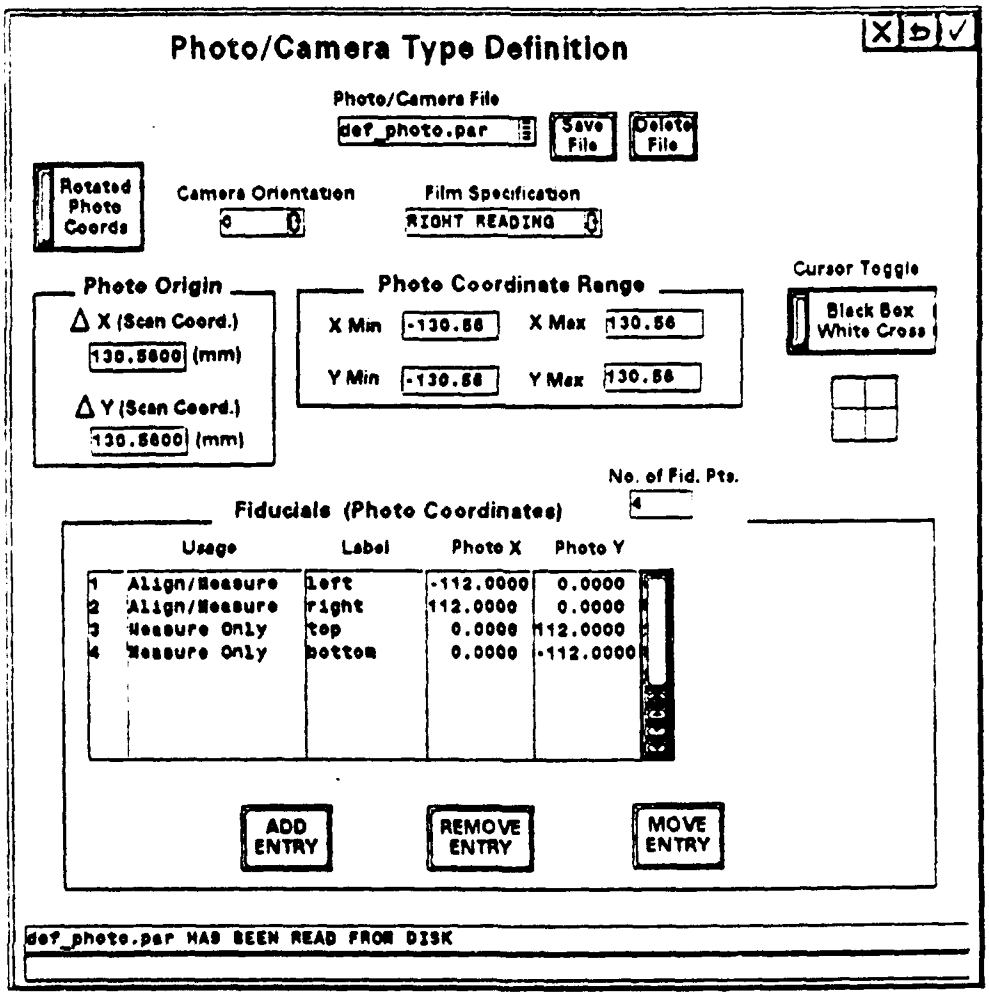
Photo/Camera Type Definition
Photo/Camera File
def_photo.par
Save File
Delete File
Rotated Photo Coords
Camera Orientation
0
Film Specification
RIGHT READING
Photo Origin
Δ X (Scan Coord.)
130.5600 (mm)
Δ Y (Scan Coord.)
130.5600 (mm)
Photo Coordinate Range
X Min -130.56
X Max 130.56
Y Min -130.56
Y Max 130.56
Cursor Toggle
Black Box
White Cross
No. of Fid. Pts.
4
Fiducials (Photo Coordinates)
Usage
Label
Photo X
Photo Y
1 Align/Measure left -112.0000 0.0000
2 Align/Measure right 112.0000 0.0000
3 Measure Only top 0.0000 112.0000
4 Measure Only bottom 0.0000 -112.0000
ADD ENTRY
REMOVE ENTRY
MOVE ENTRY
def_photo.par HAS BEEN READ FROM DISK

FIG. 2